

(12) **United States Patent**
Lu et al.

(10) **Patent No.:** **US 9,437,650 B2**
(45) **Date of Patent:** ***Sep. 6, 2016**

(54) **IMAGE DEVICE AND METHODS OF FORMING THE SAME**

(2013.01); *H01L 27/1464* (2013.01); *H01L 27/14685* (2013.01); *H01L 27/14689* (2013.01)

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(58) **Field of Classification Search**
None
See application file for complete search history.

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(56) **References Cited**

U.S. PATENT DOCUMENTS

7,642,608 B2 1/2010 Fan et al.
9,040,341 B2 * 5/2015 Lu *H01L 27/1463*
257/E31.11
2006/0244015 A1 11/2006 Rhodes

FOREIGN PATENT DOCUMENTS

TW 200847416 12/2008

* cited by examiner

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/721,782**

(22) Filed: **May 26, 2015**

(65) **Prior Publication Data**

US 2015/0255503 A1 Sep. 10, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/487,840, filed on Jun. 4, 2012, now Pat. No. 9,040,341.

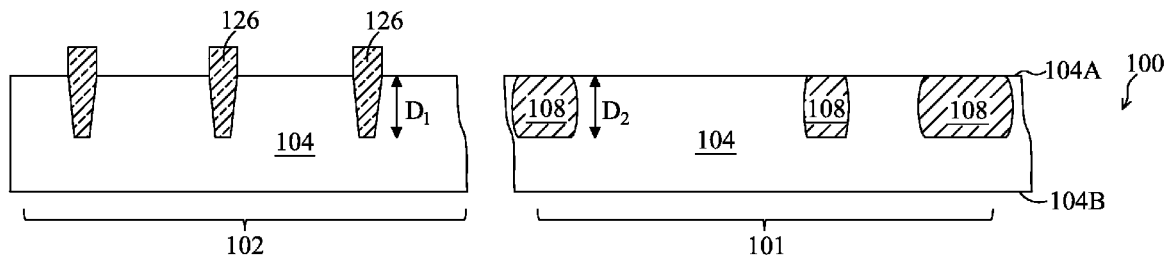
(51) **Int. Cl.**
H01L 27/14 (2006.01)
H01L 27/146 (2006.01)

(52) **U.S. Cl.**
CPC *H01L 27/14687* (2013.01); *H01L 27/1463*

(57) **ABSTRACT**

A method of forming of an image sensor device includes a patterned hardmask layer is formed over a substrate. The patterned hard mask layer has a plurality of first openings in a periphery region, and a plurality of second openings in a pixel region. A first patterned mask layer is formed over the pixel region to expose the periphery region. A plurality of first trenches is etched into the substrate in the periphery region. Each first trench, each first opening and each second opening are filled with a dielectric material. A second patterned mask layer is formed over the periphery region to expose the pixel region. The dielectric material in each second opening over the pixel region is removed. A plurality of dopants is implanted through each second opening to form various doped isolation features in the pixel region.

20 Claims, 7 Drawing Sheets



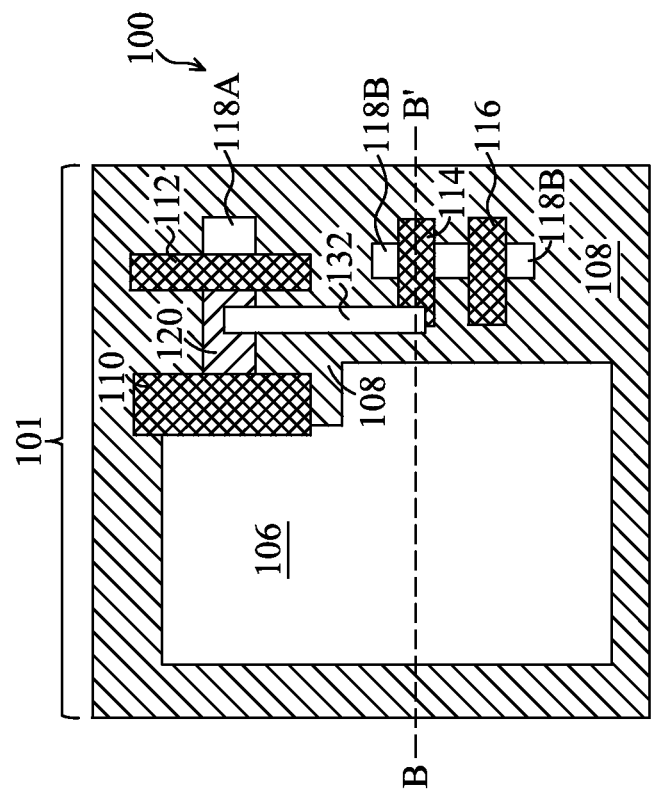


Fig. 1A

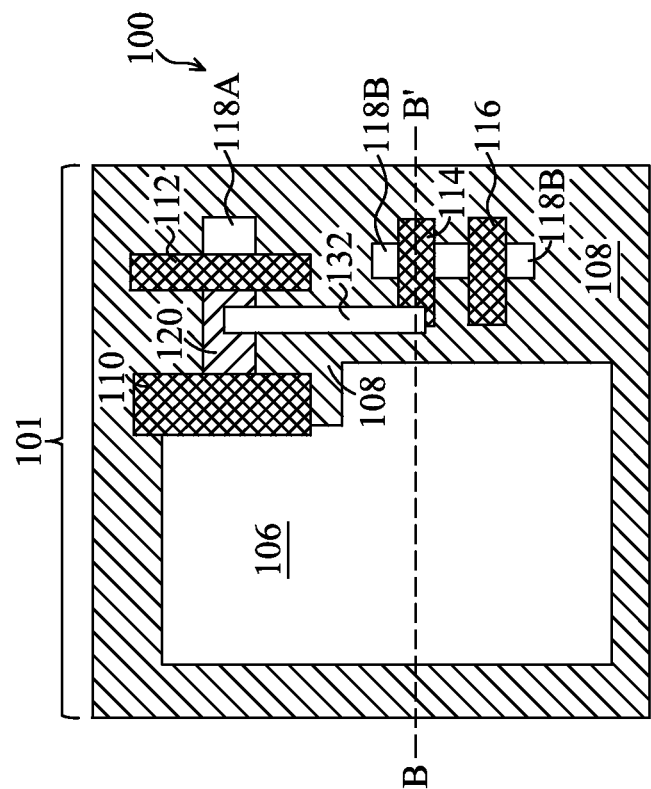


Fig. 1B

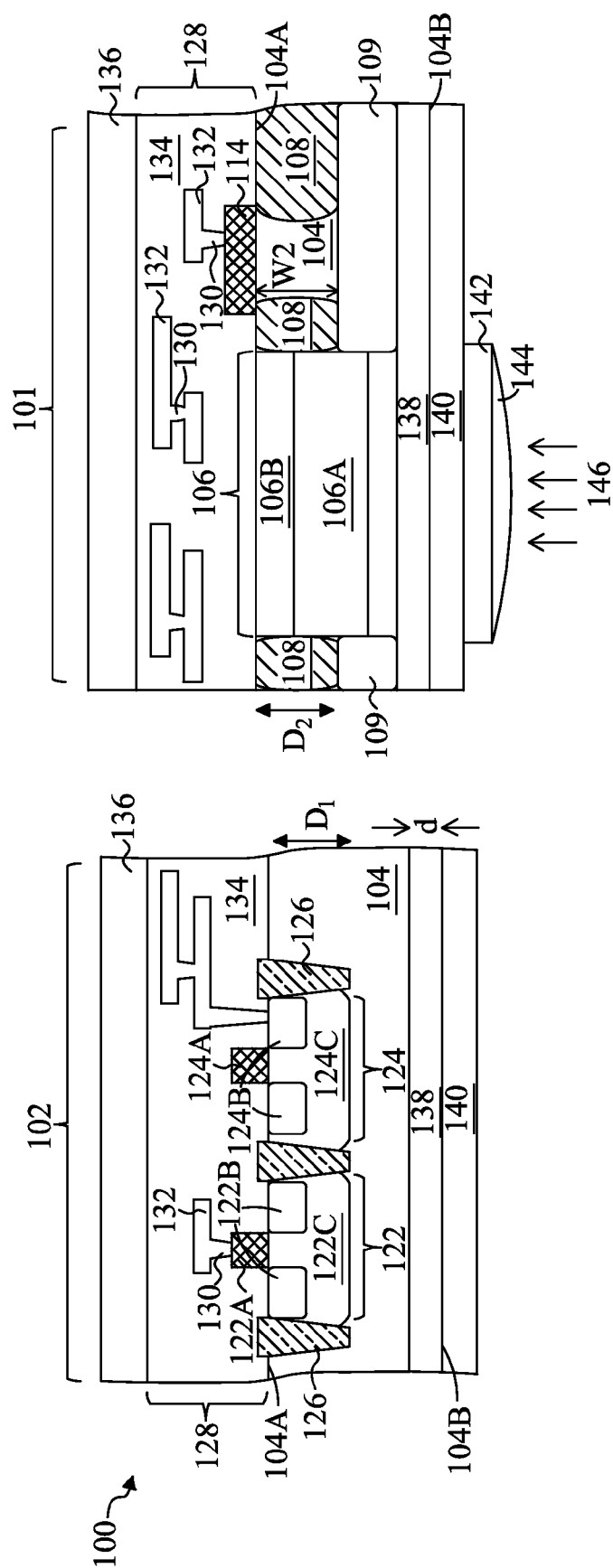


Fig. 1C

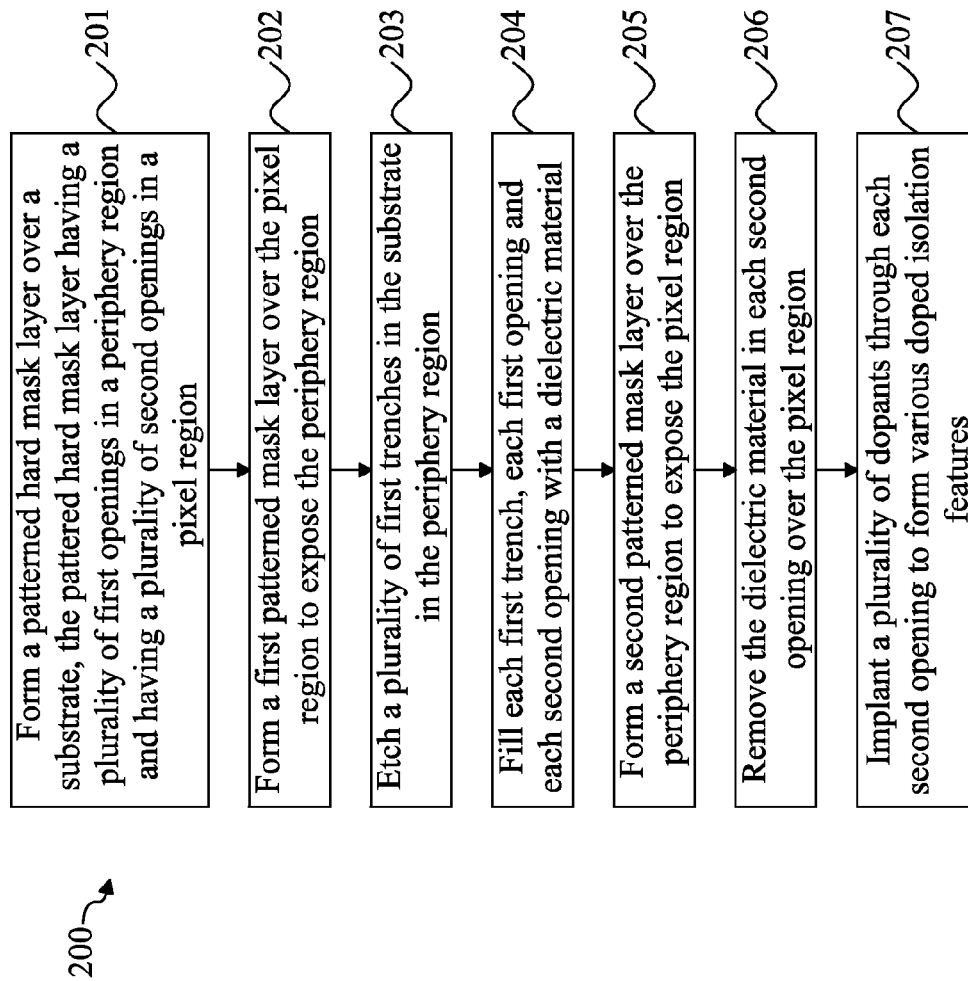


Fig. 2

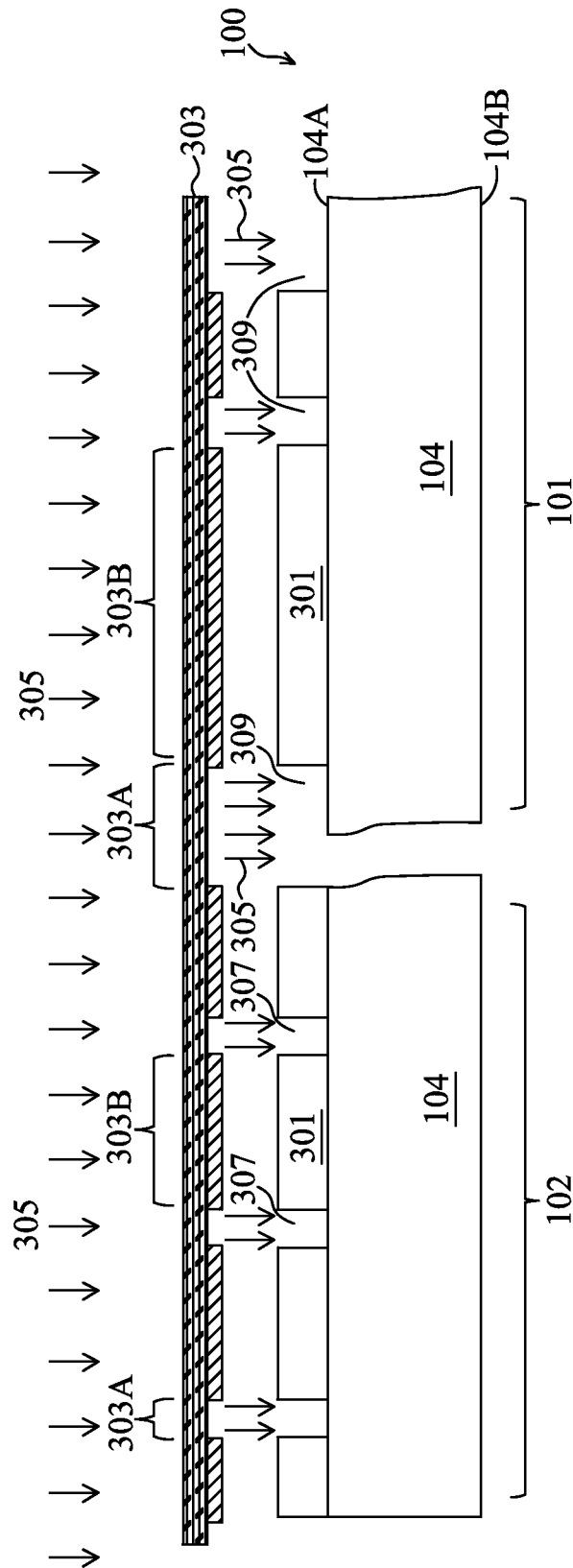


Fig. 3A

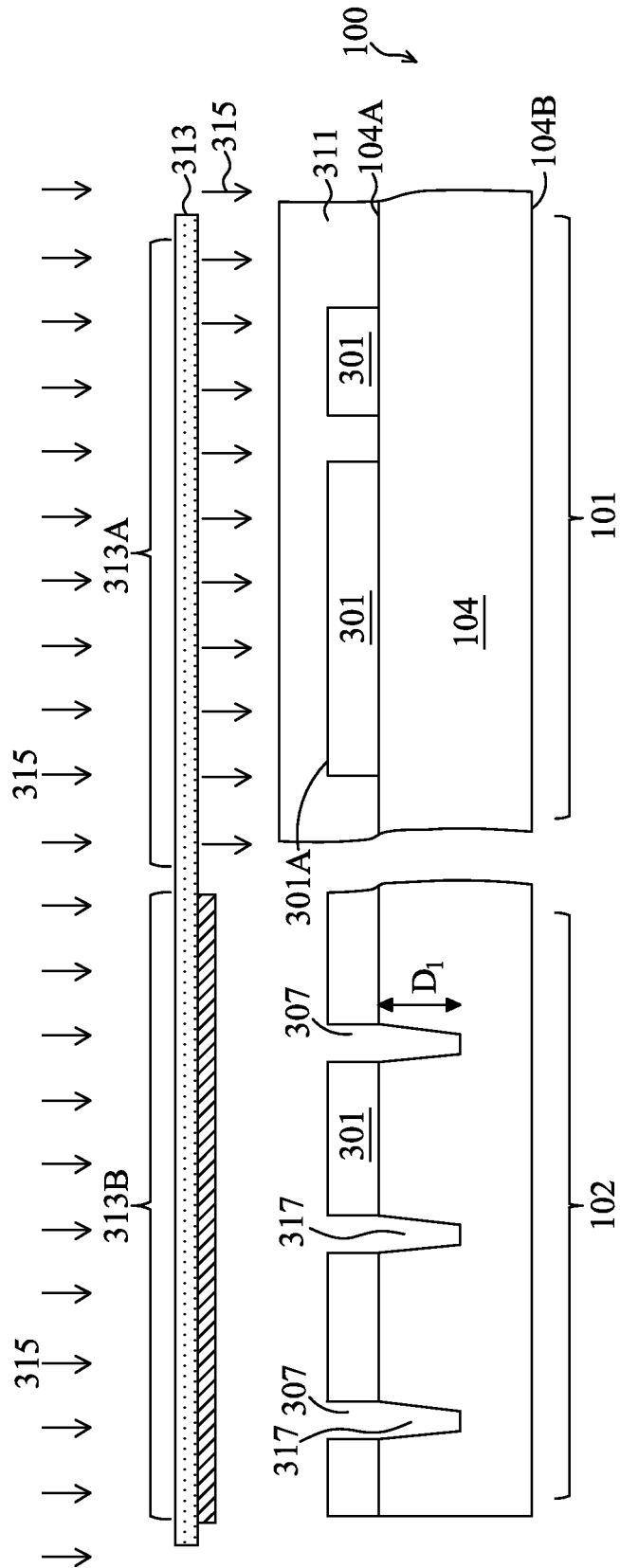


Fig. 3B

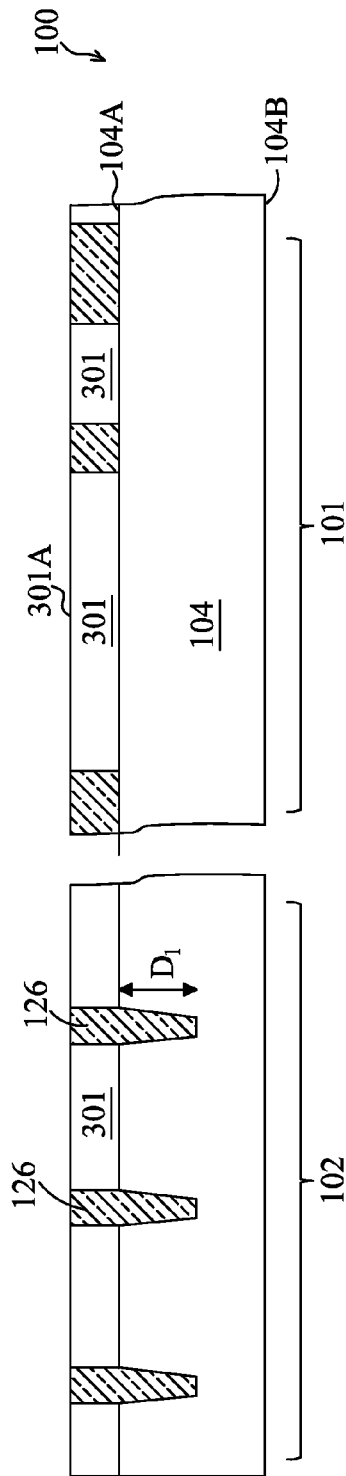


Fig. 3C

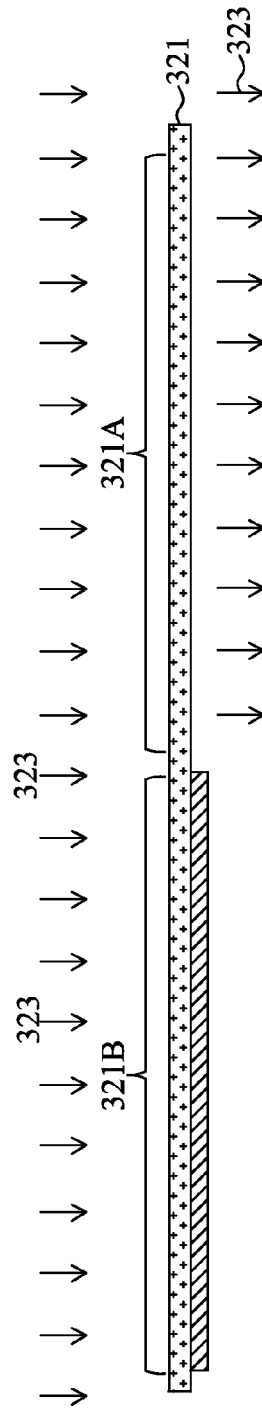


Fig. 3D

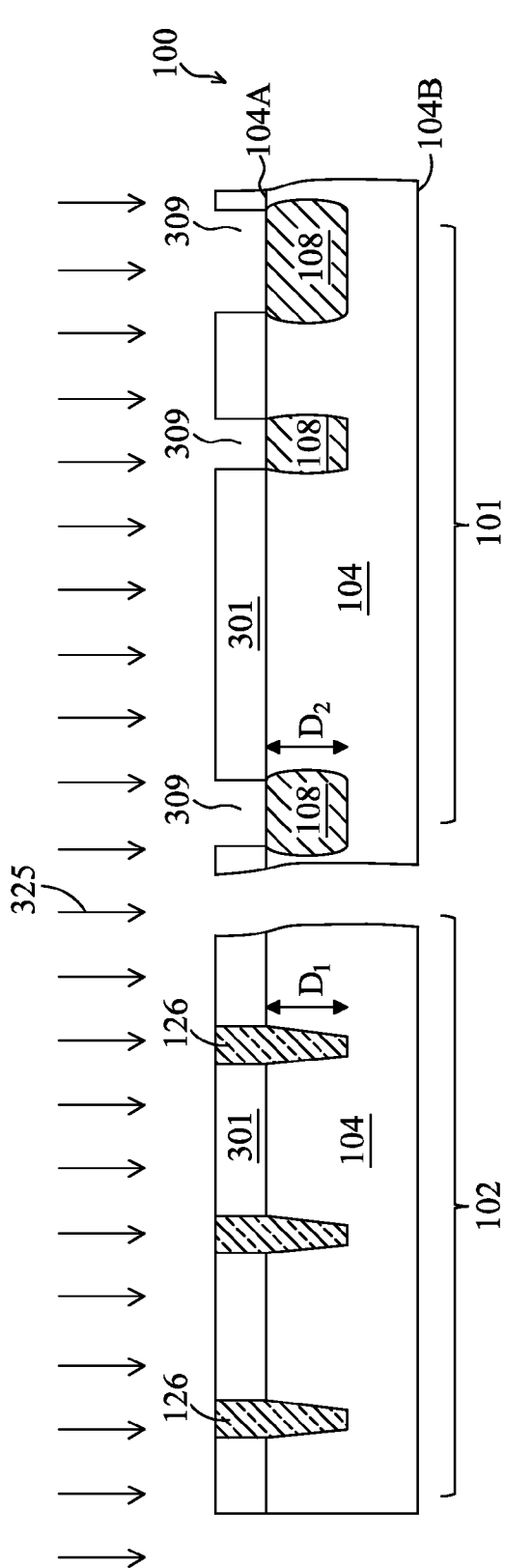


Fig. 3E

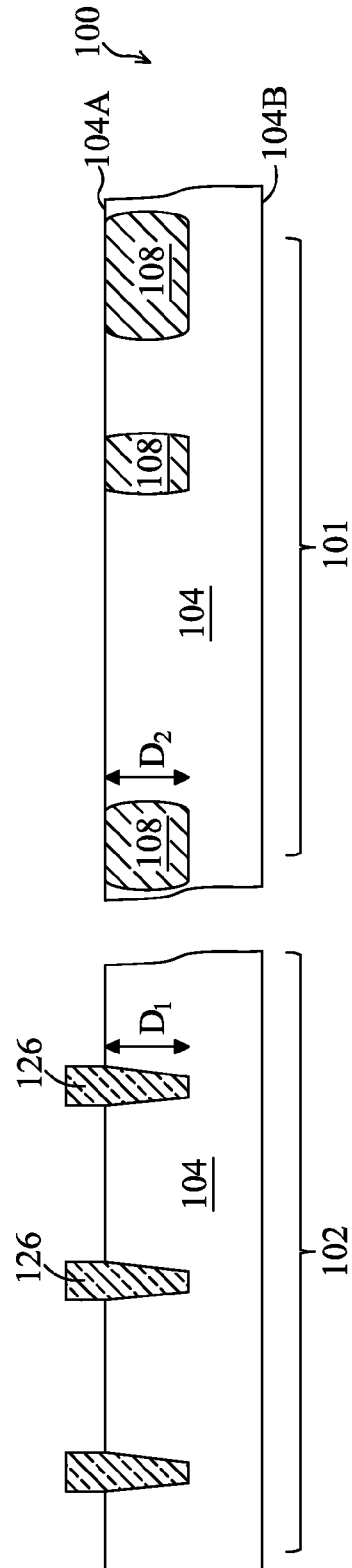


Fig. 3F

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IMAGE DEVICE AND METHODS OF FORMING THE SAME

PRIORITY CLAIM

This application claims the benefit to and is a continuation of U.S. patent application Ser. No. 13/487,840, filed on Jun. 4, 2012 and entitled "IMAGE DEVICE AND METHODS OF FORMING THE SAME" which application is incorporated herein by reference.

TECHNICAL FIELD

This disclosure relates to an image sensor device and methods for forming an image sensor device.

BACKGROUND

An image sensor device is one of the building blocks in a digital imaging system such as a digital still or video camera. An image sensor device includes a pixel array (or grid) for detecting light and recording intensity (brightness) of the detected light. The pixel array responds to the light by accumulating a charge—for example, the more light, the higher the charge. The accumulated charge is then used (for example, by other circuitry) to provide a color and brightness signal for use in a suitable application, such as a digital camera. One type of image sensor device is a backside illuminated (BSI) image sensor device. BSI image sensor devices are used for sensing a volume of light projected towards a backside surface of a substrate (which supports the image sensor circuitry of the BSI image sensor device). The pixel grid is located at a front side of the substrate, and the substrate is thin enough so that light projected towards the backside of the substrate can reach the pixel grid. BSI image sensor devices provide a reduced destructive interference, as compared to front-side illuminated (FSI) image sensor devices.

Integrated circuit (IC) technologies are constantly being improved. Such improvements frequently involve scaling down device geometries to achieve lower fabrication costs, higher device integration density, higher speeds, and better performance. Along with the advantages realized from reducing geometry size, improvements are being made directly to the image sensor devices.

Due to device scaling, improvements to image sensor device technology are continually being made to further improve image quality of image sensor devices. Although existing image sensor devices and methods of fabricating image sensor devices have been generally adequate for their intended purposes, as device scaling down continues, they have not been entirely satisfactory in all respects.

BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of the present disclosure may be understood from the following detailed description and the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. 1A is a top view of an image sensor device according to various embodiments of this disclosure.

FIG. 1B is an enlarged top view of a pixel region in the image sensor device of FIG. 1A.

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FIG. 1C is a cross sectional view of the pixel region along line B-B' in FIG. 1B and a periphery region of the image sensor device according to one or more embodiments of this disclosure.

FIG. 2 is a flowchart of a method of forming an image sensor device according to one or more embodiments of this disclosure.

FIGS. 3A to 3F are cross-sectional views of an image sensor device at various stages of manufacture according to various embodiments of the method of FIG. 2.

DETAILED DESCRIPTION

It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of the present disclosure. Specific examples of components are arrangements, which are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiment in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Further still, references to relative terms such as "top", "front", "bottom", and "back" are used to provide a relative relationship between elements and are not intended to imply any absolute direction. Various features may be arbitrarily drawn in different scales for simplicity and clarity.

FIG. 1A is a top view of an image sensor device **100** according to various aspects of the present disclosure. In the depicted embodiment, the image sensor device is a backside illuminated (BSI) image sensor device. The image sensor device **100** includes an array of pixel regions **101**. Each pixel region **101** is arranged into a column (for example, C_1 to C_x) and a row (for example, R_1 to R_y). The term "pixel region" refers to a unit cell containing features (for example, a photodetector and various circuitry), which may include various semiconductor devices for converting electromagnetic radiation to an electrical signal. Photodetectors in the pixel regions **101** may include photodiodes, complimentary metal-oxide-semiconductor (CMOS) image sensors, charged coupling device (CCD) sensors, active sensors, passive sensors, and/or other sensors. In the depicted embodiment, each pixel region **101** may include a photodetector, such as a photogate-type photodetector, for recording an intensity or brightness of light (radiation). Each pixel region **101** may also include various semiconductor devices, such as various transistors including a transfer transistor, a reset transistor, a source-follower transistor, a select transistor, other suitable transistor, or combinations thereof. Additional circuitry, inputs, and/or outputs may be in a periphery region of the image sensor device **100**. Those circuitry, inputs, and/or outputs couple to the pixel regions **101** to provide an operation environment for the pixel regions **101** and support external communications with the pixel regions **101**. For simplicity, an image sensor device including a single pixel region is described in the present disclosure; however, typically an array of such pixel regions may form the image sensor device **100** illustrated in FIG. 1.

FIG. 1B is an enlarged top view of a pixel region **101** in the image sensor device **100** on a substrate (not illustrated in FIG. 1B). The pixel region **101** refers to a unit cell containing at least one photodetector **106** and various circuitry for converting electromagnetic radiation to an electrical signal.

In the depicted embodiment, the photodetector **106** includes a photodiode for recording an intensity or brightness of light (radiation). The pixel region **101** may contain various transistors including a transfer transistor **110**, a reset transistor **112**, a source-follower transistor **114**, a select transistor **116**, or other suitable transistors, or combination thereof. The pixel region **101** may also include various doped regions in the substrate, for example doped region **118A**, **118B** and **120**. The doped regions **118A** and **118B** are configured as source/drain regions of previously mentioned transistors. The doped region **120** is also referred as a floating diffusion region **120**. The floating diffusion region **120** is between the transfer transistor **110** and the reset transistor **112**, and is one of the source/drain regions for transfer transistor **110** and the reset transistor **112**. A conductive feature **132** overlaps a portion of a gate stack of the source-follower transistor **114** and connects to the floating diffusion region **120**. The image sensor device **100** also includes various isolation features formed in the substrate to isolate various regions of the substrate to prevent leakage currents between various regions. In the depicted embodiment, a doped isolation feature **108** is formed in the pixel region **101** to isolate the photodetector **106**, the transfer transistor **110**, the reset transistor **112**, the source-follower transistor **114** and the select transistor **116**. Various dielectric isolation features **126** are formed in the periphery region as shown in FIG. 1C.

FIG. 1C is a cross sectional view of the pixel region **101** along line B-B' in FIG. 1B and a periphery region **102** of the image sensor device **100**. The image sensor device **100** includes a substrate **104** having a front surface **104A** and a back surface **104B**. In the depicted embodiment, the substrate **104** is a semiconductor substrate including silicon. Alternatively or additionally, the substrate **104** includes another elementary semiconductor, such as germanium; a compound semiconductor including silicon carbide, gallium arsenic; an alloy semiconductor including SiGe, GaAsP, AlInAs, and/or AlGaAs; or combinations thereof. The substrate **104** may be a semiconductor on insulator (SOI). The substrate **104** may have various doping configurations depending on design requirements (e.g., p-type substrate or n-type substrate). In some embodiments, the p-type refers to making holes as majority charge carriers in a semiconductor material, and the n-type refers to making electrons as majority charge carriers in a semiconductor material. In the depicted embodiment, the substrate **104** is a p-type substrate. P-type dopants that the substrate **104** is doped with include boron, gallium, indium, other suitable p-type dopants, or combinations thereof. The substrate **104** may alternatively be an n-type doped substrate. N-type dopants that the substrate **104** can be doped with include phosphorus, arsenic, other suitable n-type dopants, or combinations thereof.

The pixel region **101** includes at least one photodetector **106**, such as a photodiode, that includes a light-sensing region **106A** and a pinned layer **106B**. The light-sensing region **106A** is a doped region having a first conductivity type of dopants formed in the substrate **104**, specifically along the front surface **104A** of the substrate **104**. In the depicted embodiment, the light-sensing region **106A** is an n-type doped region. The pinned layer **106B** is a doped layer overlapping the light-sensing region **106A** at the front surface **104A** of the substrate **104**. The pinned layer **106B** has a conductivity type of dopants opposite to the light-sensing region **106A**. In the depicted embodiment, the pinned layer **106B** is a p-type implanted layer.

The pixel region **101** further includes various transistors, such as the transfer transistor **110** (shown in FIG. 1B), the reset transistor **112** (shown in FIG. 1B), the source-follower

transistor **114** and the select transistor **116** (shown in FIG. 1B). Each transistor has a corresponding gate stack disposed over the front surface **104A** of the substrate **104**. In the depicted embodiment, the gate stack of the source-follower transistor **114** overlies an isolation well region **109**. A top surface of the isolation well region **109** is away from the front surface **104A** with a distance W_2 . The distance W_2 is in a range from about 1000 Å to about 3000 Å. A bottom surface of the isolation well region **109** is substantially aligned with the back surface **104B**. The isolation well region **109** has a second conductivity type opposite to the first conductivity type of the light-sensing region **106A**. In the depicted embodiment, the isolation well region **109** is a p-type doped region. A dosage used for the isolation well region **109** is from about 1×10^{11} to 3×10^{11} atoms/cm³. The isolation well region **109** surrounds the light-sensing region **106A** of photodetector **106**. The gate stack of each transistor includes a gate dielectric layer and a gate electrode layer. The gate dielectric layer includes a dielectric material, such as silicon oxide, a high-k dielectric material, other dielectric material, or combinations thereof. Examples of high-k dielectric material include HfO₂, HfSiO, HfSiON, HfTaO, HfTiO, HfZrO, zirconium oxide, aluminum oxide, hafnium dioxide-alumina (HfO₂—Al₂O₃) alloy or combinations thereof. The gate electrode layer includes polysilicon and/or a metal including Al, Cu, Ti, Ta, W, Mo, TaN, NiSi, CoSi, TiN, WN, TiAl, TiAlN, TaCN, TaC, TaSiN or combinations thereof.

The periphery region **102** may include readout circuitry and/or control circuitry coupled to the pixel region **101** to provide an operation environment for the pixel region **101**. In the depicted embodiment, a PMOS transistor **122** and a NMOS transistor **124** are shown. The PMOS transistor **122** includes a gate stack **122A** and source/drain regions **122B** having p-type conductivity formed in a n-type well **122C**. The NMOS transistor **124** includes a gate stack **124A** and source/drain regions **124B** having n-type conductivity formed in a p-type well **124C**.

The image sensor device **100** further includes a plurality of dielectric isolation features **126** formed in substrate **104** of the periphery region **102** and a plurality of doped isolation features **108** formed in substrate **104** of the pixel region **101**. The doped isolation features **108** and the dielectric isolation features **126** isolate various regions of the substrate **104** to prevent leakage currents between various regions. In the depicted embodiment, the dielectric isolation features **126** and the doped isolation features **108** isolate the PMOS transistor **122** and the NMOS transistor **124**, the photodetector **106**, the transfer transistor **110** (shown in FIG. 1B), the reset transistor **112** (shown in FIG. 1B), the source-follower transistor **114** and the select transistor **116** (shown in FIG. 1B).

The dielectric isolation features **126** include silicon oxide, silicon nitride, silicon oxynitride, other insulating material, or combination thereof. Each of the dielectric isolation features **126** has a depth D_1 extending from the front surface **104A** into the substrate **104**. The depth D_1 is in a range of about 2000 Å to about 3500 Å.

Each of the doped isolation features **108** has a depth D_2 extending from the front surface **104A** into the substrate **104**. The depth D_2 is in a range from about 1000 Å to about 3000 Å. The doped isolation feature **108** has the second conductivity type as the isolation well region **109**. The depth D_2 of doped isolation features **108** is substantially equal to the distance W_2 of the isolation well region **109** to the front surface **104A** of the substrate **104**. The doped isolation features **108** and the isolation well regions **109** surround the

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light-sensing region **106A** of the photodetector **106** to prevent horizontal leakage paths between the photodetector **106** and other regions. In the depicted embodiment, doped isolation feature **108** is a p-type doped region. P-type dopants of the doped isolation feature **108** include boron (B), BF_2 , gallium, indium, other suitable p-type dopants or combination thereof. A dosage used for the dopants is about from about 2×10^{12} to about 8×10^{12} atoms/cm³. Alternatively, when the isolation well region **109** is a n-type doped region, doped isolation feature **108** is also a n-type doped region. N-type dopants of the doped isolation feature **108** include phosphorus, arsenic, other suitable n-type dopants or combination thereof.

The image sensor device **100** further includes a multilayer interconnect (MLI) **128** disposed over the front surface **104A** of the substrate **104**, including over the photodetector **106**. The MLI **128** is coupled to various components of the image sensor device **100**, for example the photodetector **106**, such that the various components of the image sensor device **100** are operable to properly respond to illuminated light (imaging radiation). The MLI **128** includes various conductive features **130** and **132**, which may be vertical interconnects **130**, such as contacts and/or vias **130**, and horizontal interconnects **132**, such as lines **132**. The various conductive features **130** and **132** include conductive materials, such as aluminum, aluminum/silicon/copper alloy, titanium, titanium nitride, tungsten, polysilicon, metal silicide, or combinations thereof.

The various conductive features **130** and **132** of the MLI **128** are interposed in an interlayer dielectric (ILD) layer **134**. The ILD layer **134** may include silicon dioxide, silicon nitride, silicon oxynitride, tetraethylorthosilicate (TEOS) oxide, phosphosilicate glass (PSG), borophosphosilicate glass (BPSG), fluorinated silica glass (FSG), carbon doped silicon oxide, amorphous fluorinated carbon, low-k dielectric material, polyimide, or combinations thereof. The ILD layer **134** may have a multilayer structure.

A carrier wafer **136** is disposed over the front surface **104A** of the substrate **104**. In the depicted embodiment, the carrier wafer **136** is bonded to the MLI **128**. The carrier wafer **136** includes silicon or glass. The carrier wafer **136** can provide protection for the various features (such as the photodetector **106**) formed on the front surface **104A** of the substrate **104**, and can also provide mechanical strength and support for processing the back surface **104B** of the substrate **104**.

The image sensor device **100** further includes a doped layer **138** disposed at the back surface **104B** of the substrate **104**. The doped layer **138** is formed by an implantation process, diffusion process, annealing process or combinations thereof. In the depicted embodiment, the doped layer **138** includes p-type dopants, such as boron, gallium, indium or combinations thereof. The doped layer **138** has a dopant depth, d , that extends into the substrate **104** from the back surface **104B** of the substrate **104**. The dopant depth, dopant concentration, dopant profile, or combination thereof of the doped layer **138** may be selected to optimize image quality by increasing quantum efficiency, reducing dark current or reducing white pixel defects.

The image sensor device **100** may further include an antireflective layer **140**, a color filter **142** and a lens **144** disposed over the back surface **104B** of the substrate **104**. The antireflective layer **140** includes a dielectric material, such as silicon nitride or silicon oxynitride.

The color filter **142** is disposed over the antireflective layer **140**, and is aligned with the light-sensing region **106A** of the photodetector **106**. The color filter **142** is designed to

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filter through light of a predetermined wavelength. For example, the color filter **142** may filter through visible light of a red wavelength, a green wavelength, or a blue wavelength to the photodetector **106**. In an example, the color filter **142** includes a dye-based (or pigment-based) polymer for filtering out a specific frequency band (for example, a desired wavelength of light).

The lens **144** is disposed over the color filter **142** and is also aligned with the light-sensing region **106A** of the photodetector **106**. The lens **144** may be in various positional arrangements with the photodetector **106** and color filter **142**, such that the lens **144** focuses an incident radiation **146** on the light-sensing region **106A** of the photodetector **106**. Alternatively, the position of the color filter layer **142** and the lens **144** may be reversed, such that the lens **144** is disposed between the antireflective layer **140** and color filter **142**.

In an operation of the image sensor device **100** according to one or more embodiments, the image sensor device **100** is designed to receive a radiation **146** traveling towards the back surface **104B** of the substrate **104**. The lens **144** directs the incident radiation **146** to the color filter **142**. The incident radiation **146** then passes from the color filter **142** through the antireflective layer **140** to the substrate **104** and corresponding photodetector **106**, specifically to light-sensing region **106A**. When exposed to the incident radiation **146**, the photodetector **106** responds to the incident radiation **146** by accumulating charges. When the gate of transfer transistor **110** is turned on, the charges are transferred from the photodetector **106** to the floating diffusion region **120**. Through the connection of the conductive feature **132** (shown in FIG. 1B), the source-follower transistor **114** may convert the charges from the floating diffusion region **120** to voltage signals. The select transistor **116** may allow a single row of the pixel array to be read by read-out electronics. The reset transistor **112** acts as a switch to reset the floating diffusion region **120**. When the reset transistor **112** is turned on, the floating diffusion region **120** is effectively connected to a power supply clearing all integrated charges.

FIG. 2 is a flowchart of a method **200** of forming an image sensor device according to one or more embodiments of this disclosure. The flowchart of the method **200**, at operation **201**, a patterned hard mask layer is formed over a substrate. In the depicted embodiment, the substrate has a p-type polarity. Alternatively, the substrate has an n-type polarity. The substrate has a pixel region and a periphery region. The patterned hard mask layer has a plurality of first openings in the periphery region and a plurality of second openings in the pixel region. Portions of the substrate are exposed through the plurality of first openings and the plurality of second openings. The method **200** continues with operation **202** in which a first patterned mask layer is formed over the pixel region to expose the periphery region. The first mask layer includes a first type photoresist or a dielectric layer having a different etching resistance to the underlying patterned hard mask layer. In certain embodiments, the first type photoresist is a negative photoresist. Alternatively, the first type photoresist is a positive photoresist. The method **200** continues with operation **203** in which a plurality of first trenches is etched in the substrate. Portions of the substrate exposed through the plurality of first openings in the periphery region are removed. The first patterned mask layer is removed after etching the first trenches. The method **200** continues with operation **204** in which each first trench, each first opening and each second opening is filled with a dielectric material. The method **200** continues with operation **205** in which a second patterned mask layer is formed

over the periphery region to expose the pixel region. The second patterned mask layer is over the patterned hard mask layer. The second mask layer includes a second type photoresist or a dielectric layer having a different etching resistance to the underlying patterned hard mask layer. The second type photoresist is opposite to the first type photoresist. In some embodiments, the second type photoresist is a positive photoresist. Alternatively, the second type photoresist is a negative photoresist. The method 200 continues with operation 206 in which the dielectric material in each second opening over the pixel region is removed. The method 200 continues with operation 207 in which a plurality of dopants is implanted through each second opening to form various doped isolation features in the pixel region. In the depicted embodiment, the plurality of dopants has a p-type polarity. Alternatively, the plurality of dopants has an n-type polarity. Further, it is understood that additional steps can be provided before, during, and after the method 200.

FIGS. 3A to 3F are cross-sectional views of the image sensor device 100 at various stages of manufacture according to various embodiments of the method of FIG. 2. Various figures have been simplified for a better understanding of the inventive concepts of the preset disclosure.

Referring back to FIG. 2, the method 200 proceeds from operation 201.

FIG. 3A is a cross-sectional view of the image sensor device 100 after performing operation 201. A substrate 104 has a front surface 104A and a back surface 104B. The substrate 104 is a semiconductor substrate including silicon. In the depicted embodiment, the substrate 104 is a p-type silicon substrate. P-type dopants that the substrate 104 is doped with include boron, gallium, indium, other suitable p-type dopants, or combinations thereof. Alternatively, the substrate 104 includes suitable materials mentioned in the previous paragraphs.

A hard mask layer 301 is formed over the front surface 104A of the substrate 104. The hard mask layer 301 may have multilayer structure. In some embodiments, hard mask layer 301 includes a pad layer (not shown) and a dielectric layer (not shown) over the pad layer. The pad layer, such as oxide layer, acts as a stress buffer layer between the substrate 104 and the overlying dielectric layer. The dielectric layer comprises a nitrogen-containing material, such as silicon nitride or silicon oxynitride. Alternatively, the dielectric layer includes an amorphous carbon material, silicon carbide or tetraethylorthosilicate (TEOS). The hard mask layer 301 is formed through a process such as chemical vapor deposition (CVD) or plasma enhanced chemical vapor deposition (PECVD).

Then, a first lithography patterning process is performed on the hard mask layer 301. The first lithography patterning process includes photoresist coating, soft baking, mask aligning, exposure, post-exposure baking, developing the photoresist, rinsing, drying or combinations thereof. In photoresist coating, a photoresist layer (not shown) is coated on the hard mask layer 301. In mask aligning, a photomask 303 having a mask pattern is aligned with the substrate 104. The mask pattern is designed according to integrated circuit features to be formed on a semiconductor substrate. The photomask 303 includes transparent areas 303A and non-transparent areas 303B to construct the mask pattern. In exposure, a radiation beam 305 travels through the transparent areas 303A of the photomask 303 to the underlying photoresist layer on the substrate 104. The non-transparent areas 303B block the radiation beam 305 to the underlying photoresist layer. In developing the photoresist, integrated circuit features in the photomask 303 are trans-

ferred to the underlying photoresist layer on the substrate 104. In substrate 104, a pixel region 101 and a periphery region 102 are assigned in the substrate 104. Integrated circuit features, having a plurality of first openings 307 and a plurality of second openings 309, in the photoresist layer are formed over the periphery region 102 and the pixel region 101.

Next, the hard mask layer 301 is patterned through etching processes such as reactive ion etching (RIE) by using the overlying photoresist layer as an etching mask. Integrated circuit features in the photoresist layer are transferred into the patterned hard mask layer 301. The patterned hard mask layer 301 has the plurality of first openings 307 over the periphery region 102 and the plurality of second openings 309 over the pixel region 101. Portions of the front surface 104A of the substrate 104 are exposed through the plurality of first openings 307 and the plurality of second openings 309.

Referring back to FIG. 2, the method 200 continues with operations 202 and 203. A first patterned mask layer is formed over the pixel region to expose the periphery region. A plurality of first trenches is etched in the substrate in the periphery region.

FIG. 3B is a cross-sectional view of the image sensor device 100 after performing operations 202 and 203. In operation 202, a first mask layer 311 is formed over the patterned hard mask layer 301. The first mask layer 311 overfills the first openings 307 and the second openings 309 to a level higher than a top surface 301A of the hard mask layer 301. The first mask layer 311 includes a first type photoresist 311 or a dielectric material which has different etching resistance to the underlying hard mask layer 301. The first mask layer 311 is patterned through suitable photolithographic and/or etching processes to cover the pixel region 101 and expose the periphery region 102.

In certain embodiments, the first type photoresist 311 is a negative photoresist. A second lithography patterning process is performed to coat the first type photoresist 311 on the patterned hard mask layer 301. A photomask 313 has a mask pattern with a transparent area 313A and a non-transparent area 313B used for exposure operation. During an exposure operation, a radiation beam 315 travels through the transparent area 313A of the photomask 313 to the underlying first type photoresist 311 on the substrate 104. The non-transparent area 313B blocks the radiation beam 315 to the underlying first type photoresist 311. During a development operation, the first type photoresist 311 under the transparent area 313A exposed in the radiation beam 315 is removed to cover the pixel region 101 of the substrate 104. The first type photoresist 311 under the non-transparent area 313B not exposed in the radiation beam 315 is removed to expose the periphery region 102 of the substrate 104.

Alternatively, the first type photoresist 311 is a positive photoresist. The photomask 313 used for exposure operation has an opposite tone mask pattern as shown in FIG. 3B. The transparent area covers the periphery region 102 and the non-transparent area covers the pixel region 101. Through this second lithography patterning process, the first type photoresist 311 covers the pixel region 101 and exposes the periphery region 102.

In operation 203, a plurality of first trenches 317 is etched into the substrate 104 in the periphery region 102. Portions of the substrate 104 exposed through the plurality of the first openings 307 are removed. Each of the first trenches 317 has a depth D_1 extending from the front surface 104A into the substrate 104. The depth D_1 is in a range from about 2000 Å to about 3500 Å. The pixel region 101 is covered by the

patterned mask layer **311** during etching process to form first trenches **317**. The patterned mask layer **311** is removed after operation **203**.

Referring back to FIG. 2, the method **200** continues with operation **204**. Each first trench, each first opening and each second opening are filled with a dielectric material.

FIG. 3C a cross-sectional view of the image sensor device **100** after performing operation **204**. In at least one embodiment, a dielectric material is formed overfilling each first trench **317**, each first opening **307**, each second opening **309** and the hard mask layer **301**. A planarization process, such as a chemical mechanical polishing (CMP) process and/or an etching process, is applied to the dielectric material to reduce a thickness of the dielectric material to expose the top surface **301A** of the patterned hard mask layer **301**. A plurality of the dielectric isolation features **126** are formed in the corresponding first trenches **317** and first openings **307** in the periphery region **102**. Each second opening **309** in the pixel region **101** is also filled with the dielectric material. The dielectric isolation features **126** having the same depth D_1 as the first trenches **317** electrically isolate various regions in the substrate **104**.

Referring back to FIG. 2, the method **200** continues with operations **205** and **206**. A second patterned mask layer is formed over the periphery region to expose the pixel region. The dielectric material in each second opening over the pixel region is removed.

FIG. 3D a cross-sectional view of the image sensor device **100** after performing operations **205** and **206**. In operation **205**, a second mask layer **319** is formed over the patterned hard mask layer **301**, and over the dielectric material in the first openings **307** and the second openings **309**. The second mask layer **319** includes a second type photoresist **319** or a dielectric material which has different etching resistance to the underlying hard mask layer **301**. The second mask layer **319** is patterned through suitable photolithographic and/or etching processes to cover the periphery region **102** and expose the pixel region **101**. In some embodiments, the second type photoresist **319** is opposite to the first type photoresist **311**.

In some embodiments, the second type photoresist **319** is a positive photoresist. A third lithography patterning process is performed to coat the second type photoresist **319** on the hard mask layer **301**. A photomask **321** has a mask pattern with a transparent area **321A** and a non-transparent area **321B** used for exposure operation. During an exposure operation, a radiation beam **323** travels through the transparent area **321A** of the photomask **321** to the underlying second type photoresist **319** on the substrate **104**. The non-transparent area **321B** blocks the radiation beam **323** to the underlying second type photoresist **319**. During a development operation, the second type photoresist **319** under the transparent area **321A** exposed in the radiation beam **323** is removed to expose the pixel region **101** of the substrate **104**. The second type photoresist **319** under the non-transparent area **321B** not exposed in the radiation beam **323** is remained to cover the periphery region **102** of the substrate **104**.

Alternatively, the second type photoresist **319** is a negative photoresist. The photomask **321** used for exposure operation has an opposite tone mask pattern as shown in FIG. 3D. The transparent area covers the periphery region **102** and the non-transparent area covers the pixel region **101**. Through this third lithography patterning process, the patterned second type photoresist **319** covers the periphery region **102** and exposes the pixel region **101**.

Advantageously, the second type photoresist **319** is opposite to the first type photoresist **311**. During the second and

the third lithography patterning processes, the photomask **313** and the photomask **321** could be the same photomask. By using different type photoresists **311** and **319**, the second and the third lithography patterning processes can use the same photomask to cover either the periphery region **102** or the pixel region **101** in operations **202** and **205**. This disclosure may reduce the cost in lithography patterning processes by using the same photomask layer for different process operations.

In other embodiments, the second and the third lithography patterning processes may use different photomasks or a same type of photoresist depending on process requirements.

In operation **206**, the dielectric material in each second opening **309** over the pixel region **101** is removed. Portions of the substrate **104** are exposed through the plurality of the second openings **309**. The periphery region **102** is covered by the second mask layer **319** during the dielectric material removing process. The second mask layer **319** may be removed after operation **206**.

Referring back to FIG. 2, the method **200** continues with operation **207**. A plurality of dopants is implanted through each second opening to form various doped isolation features in the pixel region.

FIG. 3E a cross-sectional view of the image sensor device **100** after performing operation **207**. A plurality of dopants **325** is implanted through each second opening **309** into the pixel region **101** of the substrate **104** to form various doped isolation features **108**. The plurality of dopants **325** has a second conductivity type. Doped isolation features **108** are formed to surround active areas of the transistors (**110**, **112**, **114** and **116** in FIG. 1B) not covered by the patterned hard mask layer **301**. In the depicted embodiment, doped isolation feature **108** is a p-type doped region. P-type dopants of the doped isolation feature **108** include boron (B), BF_2 , gallium, indium, other suitable p-type dopants or combination thereof. A dosage used for the dopants is from about 2×10^{12} to about 8×10^{12} atoms/cm³. Each of the doped isolation features **108** has a depth D_2 extending from the front surface **104A** into the substrate **104**. The depth D_2 is in a range of about 1000 Å to about 3000 Å. The doped isolation features **108** surround the active areas of the transistors (**110**, **112**, **114** and **116** in FIG. 1B) and also surround the light-sensing region **106A** of the photodetector **106** (shown in FIGS. 1B and 1C). The possible horizontal leakage paths between the photodetector **106** and the transistors (**110**, **112**, **114** and **116** in FIG. 1B) may be eliminated. When the depth D_2 is less than 1000 Å, the doped isolation feature **108** could not electrically isolate various regions. Hence, the device performance of the image sensor device **100** may reduce. When the depth D_2 is larger than 3000 Å, the hard mask layer **301** does not effectively protect the underlying substrate **114** from damage during the high energy implantation process to achieve the depth D_2 .

It is understood that additional steps can be provided before, during, and after the operation **207** of the method **200**. For example, FIG. 3F is a cross-sectional view of the image sensor device **100** after the operation **207**. The hard mask layer **301** is removed after the doped isolation feature **108** formation. The dielectric isolation features **126** may be further planarized to reduce a height of the dielectric isolation features **126** above the front surface **104** of the substrate **104**.

Additional steps may be performed to achieve the image sensor device **100** as shown in FIG. 1C. The image sensor device **100** further includes a photodetector **106**, such as a photodiode, that includes a light-sensing region **106A** and a

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pinned layer **106B**. The light-sensing region **106A** is a doped region having a first conductivity type of dopants formed in the substrate **104**, specifically along the front surface **104A** of the substrate **104**. The first conductivity type of the light-sensing region **106A** is opposite to the second conductivity type of the doped isolation feature **108**. In the depicted embodiment, the light-sensing region **106A** is an n-type doped region. The pinned layer **106B** is a doped layer overlapping the light-sensing region **106A** at the front surface **104A** of the substrate **104**. The pinned layer **106** has a conductivity type of dopants opposite to the light-sensing region **106A**. In the depicted embodiment, the pinned layer **106B** is a p-type implanted layer.

An isolation well region **109** having the second conductivity type may be formed in the pixel region **101**. The isolation well region **109** has the second conductivity type as the doped isolation feature **108**. The isolation well region **109** is beneath the front surface **104A** of the substrate with a distance W_2 . The distance W_2 is in a range from about 1000 Å to about 3000 Å. A bottom surface of the isolation well region **109** is substantially identical to the back surface **104B** of the substrate **104**. The distance W_2 of the isolation well region **109** to the front surface **104A** of the substrate **104** is substantially equal to the depth D_2 of doped isolation features **108**. As shown in FIG. 1C, the doped isolation features **108** and the isolation well regions **109** surround the light-sensing region **106A** of the photodetector **106** to prevent horizontal leakage paths between the photodetector **106** and other regions. The isolation well region **109** is formed by lithography patterning and implantation process. In the depicted embodiment, the isolation well region **109** is a p-type doped region. P-type dopants of the isolation well region **109** include as boron, gallium, indium or combinations thereof. A dosage used for the dopants is from about 1×10^{11} atoms/cm³ to about 3×10^{11} atoms/cm³. Alternatively, the isolation well region **109** is a n-type doped region including n-type dopants such as phosphorus, arsenic, other suitable n-type dopants or combination thereof.

In the periphery region **102**, a n-type well **122C** and a p-well **124C** are formed in the substrate **104** by implantations. Source/drain regions **122B** and source/drain regions **124B** are formed in the corresponding n-type well **122C** and p-well **124** by implantations.

A plurality of gate stacks **114**, **122A** and **124B** are formed on the front surface **104A** of the substrate **104**. The gate stack **114** corresponds to a source-follower transistor **114** in the pixel region **101**. The gate stacks **122A** and **124B** correspond to the n-type well **122C** and the p-well **124C** in the periphery region **102**. The gate stacks **122A** and source/drain regions **122B** in the n-type well **122C** construct a PMOS transistor. Likewise, the gate stacks **124A** and source/drain regions **124B** in the p-type well **124C** construct a NMOS transistor. The gate stacks **114**, **122A** and **124B** are formed by suitable process, including deposition, lithography patterning, and etching processes.

The image sensor device **100** further includes a multilayer interconnect (MLI) **128** disposed over the front surface **104A** of the substrate **104**. The MLI **128** is coupled to various components of the image sensor device **100**, such as the photodetector **106**. The MLI **128** includes various conductive features, which may be vertical interconnects, such as contacts and/or vias **130**, and horizontal interconnects, such as lines **132**. The conductive features **130** and **132** are formed by suitable process, including deposition, lithography patterning, and etching processes to form vertical and horizontal interconnects.

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The various conductive features **130** and **132** of the MLI **128** are disposed in an interlayer dielectric (ILD) layer **134**. The ILD layer **134** may have a multilayer structure. The ILD layer **134** may be formed by suitable process, including chemical vapor deposition (CVD) or plasma enhanced chemical vapor deposition (PECVD). In one example, the MLI **128** and the ILD layer **134** may be formed in an integrated process including a damascene process.

In some embodiments, further process steps are included after the MLI **128** formation. As illustrated in FIG. 1C, a carrier wafer **136** is bonded to the MLI **128**. The carrier wafer **136** provides mechanical strength and support for processing the back surface **104B** of the substrate **104**. A planarization process, such as a chemical mechanical polishing (CMP) process, is applied to the back surface **104B** of the substrate **104** to reduce a thickness of the substrate **104**. A doped layer **138** is formed by an implantation process, diffusion process, annealing process or combinations thereof through the back surface **104B**. The doped layer **138** may recover the back surface **104B** damage during the planarization process, and reduce dark current and white pixels. An antireflective layer **140**, a color filter **142** and a lens **144** disposed over the back surface **104B** of the substrate **104**. The color filter **142** and the lens **144** are aligned with the light-sensing region **106A** of the photodetector **106**.

Various embodiments of the present disclosure may be used to improve the performance of an image sensor device. For example, the doped isolation feature **108** is formed in the pixel region **101** by implantation processes. This disclosure eliminates the drawbacks in conventional methods with etching damages during the shallow trench isolation (STI) formation in the pixel region. Without etching damages, this disclosure could reduce dark current or reduce white pixel defects of the image sensor device. In another example, the first openings **307** and the second openings **309** are defined in integrated circuit features of the same photomask **303**. The first openings **307** and the second openings **309** are formed over the substrate **104** through the same first lithography patterning process. The dielectric isolation features **126** and doped isolation features **108** are later formed in the corresponding first openings **307** and second openings **309** in the periphery region **102** and the pixel region **101**. Through the same first lithography patterning process to define the locations of the first openings **307** and the second openings **309**, this disclosure eliminates the overlay issue that may happen between dielectric isolation features **126** and doped isolation features **108**. As device scaling down continues, the locations of dielectric isolation features **126** and doped isolation features **108** are accurately controlled to isolate various regions of the substrate to prevent leakage currents between various regions.

One aspect of the disclosure describes a method of forming an image sensor device. A patterned hard mask layer is formed over a substrate. The patterned hard mask layer has a plurality of first openings in a periphery region of the substrate, and a plurality of second openings in a pixel region of the substrate. A first patterned mask layer is formed over the pixel region to expose the periphery region. A plurality of first trenches is etched into the substrate in the periphery region. Each first trench, each first opening and each second opening are filled with a dielectric material. A second patterned mask layer is formed over the periphery region to expose the pixel region. The dielectric material in each second opening over the pixel region is removed. A plurality of dopants is implanted through each second opening to form various doped isolation features in the pixel region.

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A further aspect of the disclosure describes a method of forming an image sensor device. A substrate includes a front surface and a back surface, and a pixel region and a periphery region. A patterned hard mask layer is formed over the front surface of the substrate. The patterned hard mask layer has a plurality of first openings in the periphery region, and a plurality of second openings in the pixel region. A first patterned mask layer is formed over the patterned hard mask layer in the pixel region to expose the periphery region. A plurality of first trenches is etched from the front surface in the periphery region. Each first trench, each first opening and each second opening are filled with a dielectric material. A second patterned mask layer is formed over the patterned hard mask layer in the periphery region to expose the pixel region. The dielectric material in each second opening over the pixel region is removed. A plurality of dopants is implanted through each second opening to form various doped isolation features in the pixel region. At least one photodetector is formed in the substrate of the pixel region. The at least one photodetector is surrounded by the doped isolation features. A color filter and a lens are formed over the back surface of the substrate. The color filter and the lens are aligned with the at least one photodetector.

Another aspect of the disclosure describes a method of forming an image sensor device. A substrate includes a front surface and a back surface, and a pixel region and a periphery region. A patterned hard mask layer is formed over the front surface of the substrate. The patterned hard mask layer has a plurality of first openings in the periphery region, and a plurality of second openings in the pixel region. A first patterned photoresist is formed over the patterned hard mask layer in the pixel region to expose the periphery region. A plurality of first trenches is etched from the front surface in the periphery region. Each first trench, each first opening and each second opening are filled with a dielectric material. A second patterned photoresist is formed over the patterned hard mask layer in the periphery region to expose the pixel region. The dielectric material in each second opening over the pixel region is removed. A plurality of dopants is implanted through each second opening to form various doped isolation features in the pixel region. At least one photodetector is formed in the substrate of the pixel region. The at least one photodetector is surrounded by the doped isolation features. A doped layer is formed in the back surface of the substrate.

Embodiments described herein may provide for a method of forming an image sensor device. The method includes forming a patterned hard mask layer over a substrate, wherein the patterned hard mask layer has a plurality of first openings in a periphery region of the substrate, and a plurality of second openings in a pixel region of the substrate. The substrate is etched through the plurality of first openings to form a plurality of first trenches in the substrate. Each trench, each first opening and each second opening is filled with a material, and the material is removed in each second opening over the pixel region. The method further includes implanting dopant through each second opening to form doped isolation features in the pixel region.

In another aspect, embodiments described herein may provide for method of forming an image sensor device that includes providing a substrate having a front surface and a back surface, and a pixel region and a periphery region, and forming a patterned hard mask layer over the front surface of the substrate, wherein the patterned hard mask layer has a first opening in the periphery region, and a second opening in the pixel region. A trench is etched in the front surface of the substrate in the periphery region through the first open-

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ing. The method includes filling the trench, the first opening and the second opening with a material, removing the material in the second opening over the pixel region, while leaving the material intact in the trench. The method also includes implanting a dopant through the second opening to form a doped isolation feature in the pixel region.

In yet another aspect, embodiments described herein may provide for a method of forming an image sensor device on a providing a substrate having a front surface and a back surface, and a pixel region and a periphery region. The method includes forming a patterned hard mask layer over the front surface of the substrate, wherein the patterned hard mask layer has a first opening in the periphery region, and a second opening in the pixel region. The method further includes forming a first patterned photoresist covering the patterned hard mask layer in the pixel region and exposing the patterned hard mask in the periphery region. A trench is etched through the first opening. The trench, the first opening and the second opening are filled with a dielectric material. A second patterned photoresist is formed over the patterned hard mask layer covering the periphery region and exposing the pixel region. The method further includes removing the dielectric material in the second opening, and implanting a dopant through the second opening into the substrate to form a doped isolation feature in the pixel region.

Although the embodiments and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. As one of ordinary skill in the art will readily appreciate from the present disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed:

1. A method of forming an image sensor device, the method comprising:

forming a patterned hard mask layer over a substrate, wherein the patterned hard mask layer has a plurality of first openings in a periphery region of the substrate, and a plurality of second openings in a pixel region of the substrate;

etching the substrate through the plurality of first openings to form a plurality of first trenches in the substrate; filling each first trench, each first opening and each second opening with a material;

removing the material in each second opening over the pixel region; and

implanting dopant through each second opening to form doped isolation features in the pixel region.

2. The method of claim 1, wherein the material is a dielectric material.

3. The method of claim 1, wherein forming a patterned hard mask comprises etching a hard mask through a patterned photoresist layer.

4. The method of claim 1, further comprising:

forming at least one photodetector in the pixel region, wherein the at least one photodetector is surrounded by the doped isolation features; and

forming a doped layer in a back surface of the substrate.

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5. The method of claim 4, further comprising: forming a color filter and a lens over the back surface of the substrate, wherein the color filter and the lens are aligned with the at least one photodetector.

6. The method of claim 1, further comprising forming a light-sensing region in the pixel region surrounded by the doped isolation features.

7. The method of claim 6, wherein the light-sensing region has a first conductivity type and the doped isolation features have a second conductivity type opposite to the first conductivity type.

8. The method of claim 1, further comprising:
defining the patterned hard mask layer by a first photomask.

9. A method of forming an image sensor device, the method comprising:

providing a substrate having a front surface and a back surface, and a pixel region and a periphery region;

forming a patterned hard mask layer over the front surface of the substrate, wherein the patterned hard mask layer has a first opening in the periphery region, and a second opening in the pixel region;

etching a trench in the front surface of the substrate in the periphery region through the first opening;

filling the trench, the first opening and the second opening with a material;

removing the material in the second opening over the pixel region, while leaving the material intact in the trench; and

implanting a dopant through the second opening to form a doped isolation feature in the pixel region.

10. The method of claim 9, further comprising: forming at least one photodetector in the substrate of the pixel region, wherein the at least one photodetector is surrounded by the doped isolation features; and

forming a color filter and a lens over the back surface of the substrate, wherein the color filter and the lens are aligned with the at least one photodetector.

11. The method of claim 9, further comprising:
forming a first patterned mask layer over the patterned hard mask layer in the pixel region to expose the periphery region; and

forming a second patterned mask layer over the patterned hard mask layer in the periphery region to expose the pixel region.

12. The method of claim 11, wherein the first mask layer is one of a positive photoresist or a negative photoresist, and

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the second mask layer is the opposite one of a positive photoresist or a negative photoresist.

13. The method of claim 9, further comprising forming at least one light-sensing region in the pixel region surrounded by the doped isolation features.

14. The method of claim 13, wherein at least one light-sensing region has a first conductivity type and the doped isolation features have a second conductivity type opposite to the first conductivity type.

15. The method of claim 9, further comprising:
defining the patterned mask layer by a first photomask.

16. The method of claim 9, wherein the trench extends into the substrate with a depth of from about 2000 Å to about 3500 Å.

17. The method of claim 9, wherein the doped isolation feature extends into the substrate with a depth of from about 1000 Å to about 3000 Å.

18. A method of forming an image sensor device, the method comprising:

providing a substrate having a front surface and a back surface, and a pixel region and a periphery region;

forming a patterned hard mask layer over the front surface of the substrate, wherein the patterned hard mask layer has a first opening in the periphery region, and a second opening in the pixel region;

forming a first patterned photoresist covering the patterned hard mask layer in the pixel region and exposing the patterned hard mask in the periphery region;

etching a trench through the first opening;

filling the trench, the first opening and the second opening with a material;

forming a second patterned photoresist over the patterned hard mask layer covering the periphery region and exposing the pixel region;

removing the material in the second opening; and
implanting a dopant through the second opening into the substrate to form a doped isolation feature in the pixel region.

19. The method of claim 18, further comprising:

forming at least one photodetector in the substrate of the pixel region, wherein the at least one photodetector is surrounded by the doped isolation features; and

forming a doped layer in the back surface of the substrate.

20. The method of claim 18, wherein the dopant comprises boron (B), BF₂, gallium, indium or combination thereof.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 9,437,650 B2
APPLICATION NO. : 14/721782
DATED : September 6, 2016
INVENTOR(S) : Wen-Chen Lu

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title page, Item (73) Assignee, Line 1, delete “Taiwam” and insert --Taiwan--.

Signed and Sealed this
Twenty-ninth Day of November, 2016

A handwritten signature in black ink, reading "Michelle K. Lee". The signature is fluid and cursive, with the first letters of each name being capitalized and prominent.

Michelle K. Lee
Director of the United States Patent and Trademark Office